# Status of the experiment on observation of Goos-Hänchen effect with neutrons

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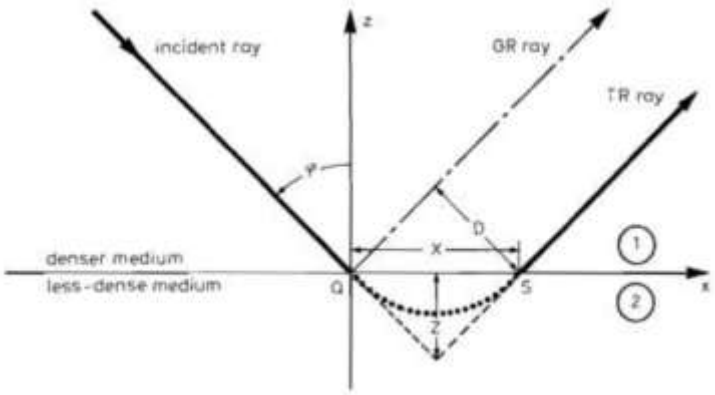
## *Goos – Hänchen effect – Longitudinal shift of the wave beam at total reflection*




Total inner reflection

*F. Goos und H. Hänchen, Ann. der Phys. 1, 333 (1947).*

*F. Goos und H. Lindberg-Hanchen, Ann. der Phys. 5, 251 (1949)*

***The effect has general nature***

**A. Schoch, Acustica 2, 1 (1952) - Acoustic waves**

**V. Akylas, J. Kaur and T.M. Knasel, Appl. Opt. 13, 742 (1974) - Microwaves**

**Tamasaku K., Ishikawa T., Acta Cryst. A 58 408 (2002) – X -rays**

# Goos - Hänchen shift and neutron optics

## Proposals & Theory


1. A.A. Seregin. *Surface shift of neutron at reflection*. Yadernaya Physica [ Sov. Journ. Nuclear Physics] 33, 1173 (1981).

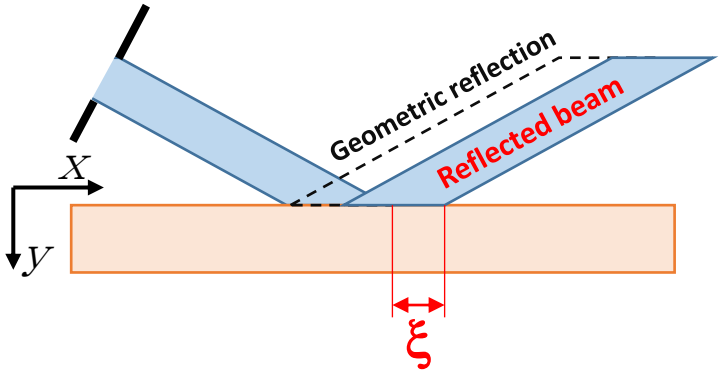
2. M. Maaza, B.Pardo. *On the possibility to observe the longitudinal Goos-Hänchen shift with cold neutrons*. Opt.Comm. 142, 84 (1997).

3. V.K. Ignatovich. *Neutron reflection from condensed matter, the Goos–Hänchen effect and coherence.* Phys. Lett. A, 36, 322 (2004).

4. A.I. Frank , *On the Goos-Hänchen effect in neutron optics*, Journal of Physics Conference Series, 528, 012029 (2014)


## Attempts of the experimental observation


4. V.-O. de Haan, J.Plomp, Th. M. Rekveldt, W. H. Kraan, and Ad A. Van Well. *Observation of the Goos-Hänchen Shift with Neutrons.* Phys.Rev.Lett. 010401 (2010). Pseudo-Larmor precession.




**Artmann formula**

$$\xi = -\frac{d\varphi}{dk_x} \rightarrow \xi = \frac{\hbar k_x}{m}\hbar\frac{d}{dE_y} \quad v_x\tau$$

**Group delay time**

**Typical group delay time $\tau$ at total reflection is ~ $5 \times 10^{-9}$ sec**

**For cold neutrons the longitudinal shift $\xi$ is about some μm**

**Difficult to observe**

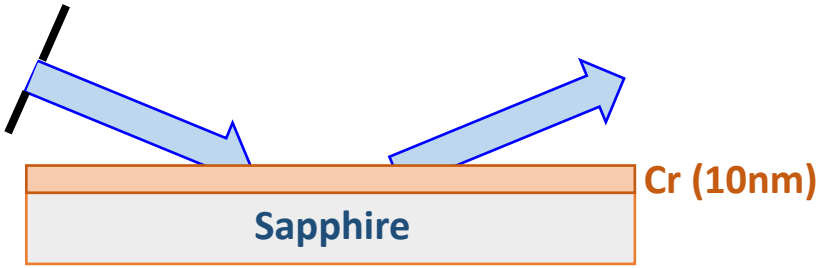
## Solution: Reflection from multilayer structures

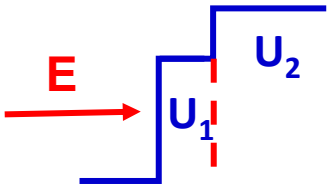
*T. Tamir, H. L. Bertoni, J. Opt. Soc. Am. 61, 1397 (1971)*

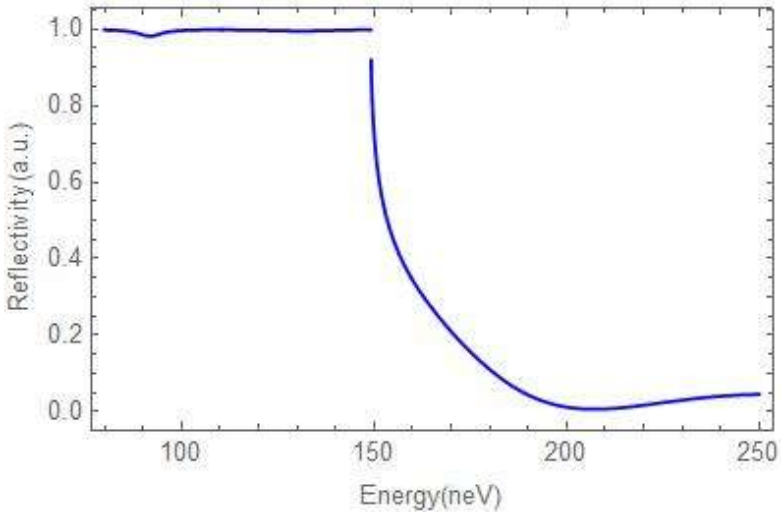
*V. K. Ignatovich, 2004*

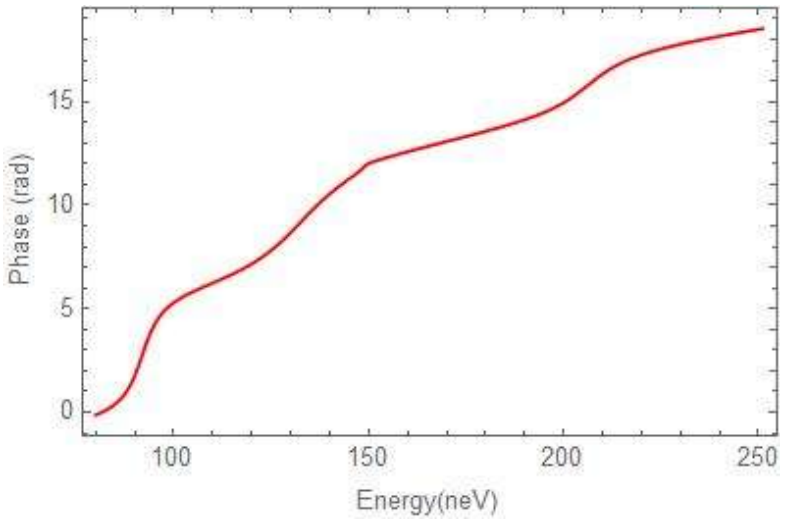
*A. I. Frank, J. Phys.: Conf. Ser. 528, 012029 (2014)*

# Sample - Chromium film on sapphire

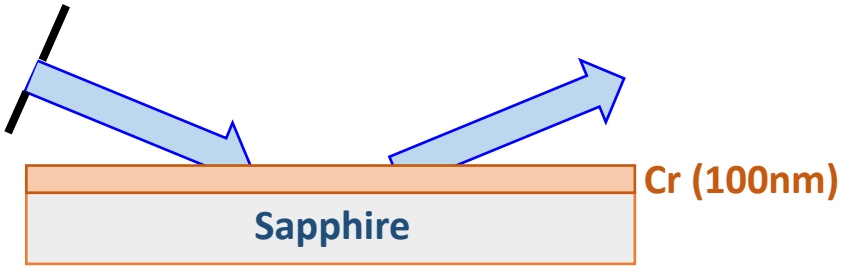


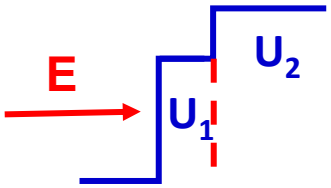



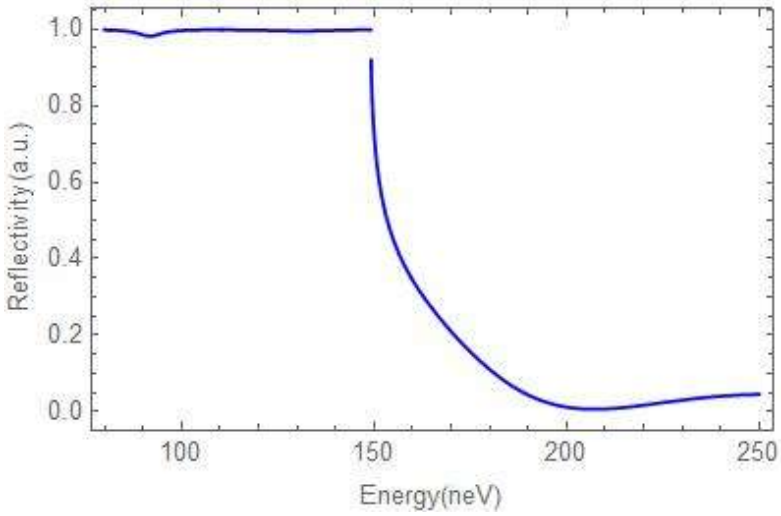



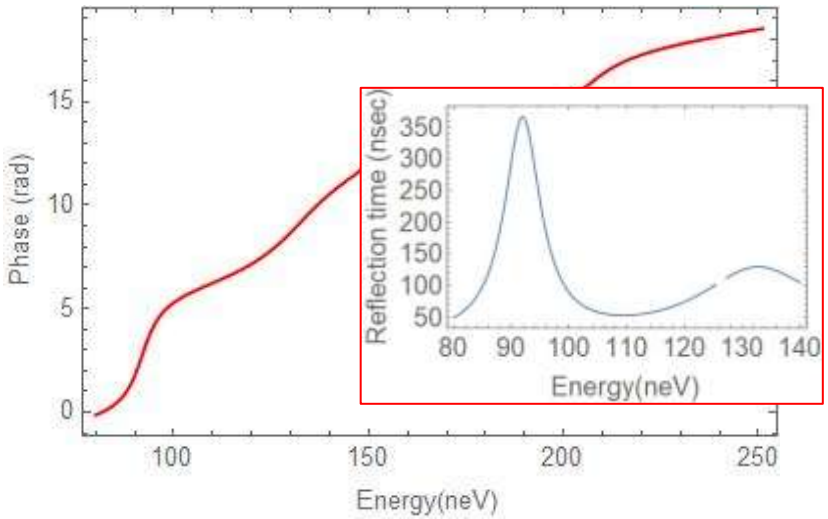



# Sample - Chromium film on sapphire



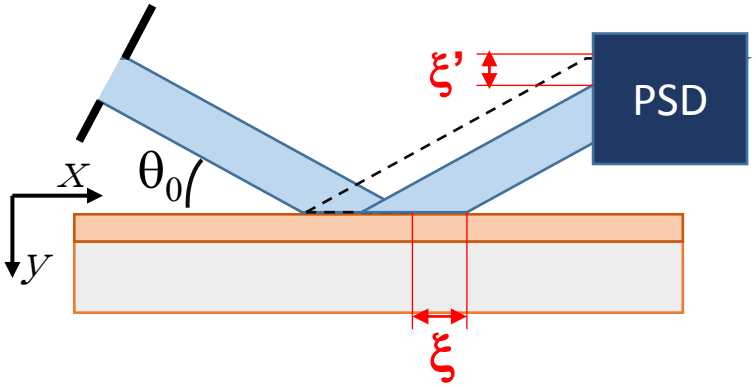

**Typical group delay time at total reflection in the resonance is ~ $3.5 \times 10^{-7}$ sec**

**For cold neutrons the longitudinal shift $\xi$ is ~ 0.35 mm**

**Effect in resonance and out of resonance can be compared**

# How to measure

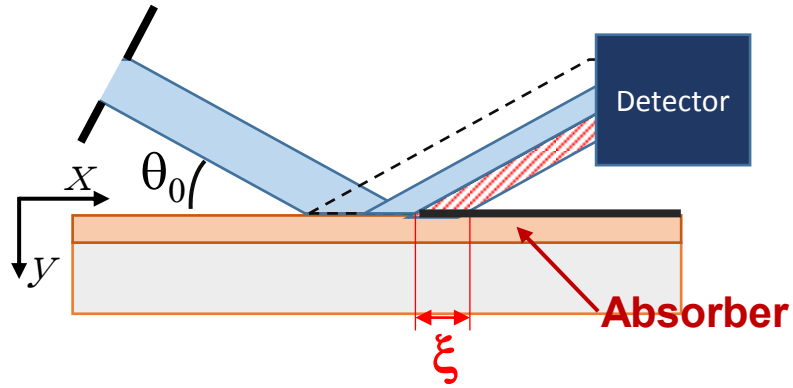
## Measure the transverse shift related with the longitudinal one



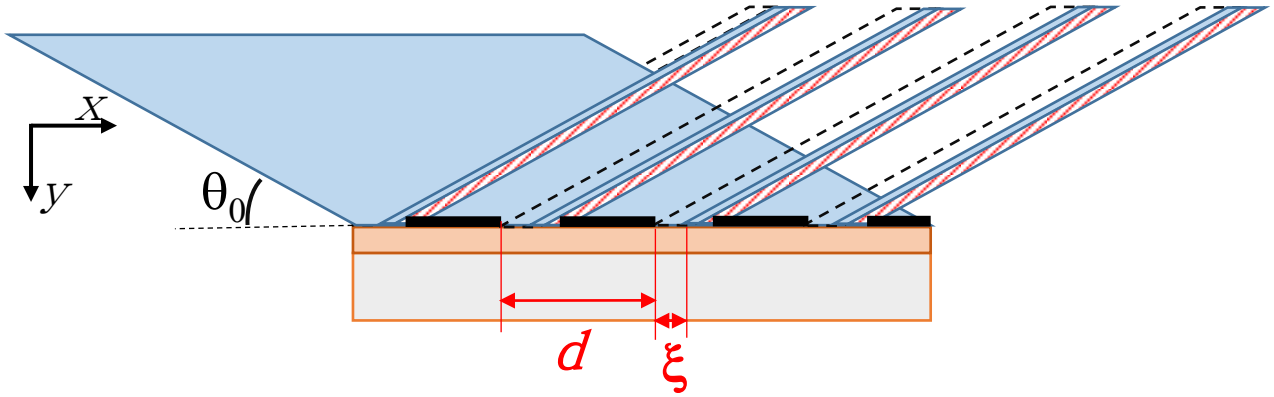

$$\xi' = \xi \cos(\theta_0) = \xi \frac{v_y}{v_x} = v_y \tau$$

$V_y$~ 5m/sec and ξ' ~ some μm

## Use an absorber to measure a deficit of the neutron intensity due to longitudinal shift



# An absorbing macro-grating (system of slits)




**Is this diffraction grating or some system of slits?**

$\frac{\lambda}{\theta_0 d}$ □ **angular divergence of the reflectometer beam**

**For λ~4Å, $\theta_0$~5 mrad and angular divergence Δθ~ 0.7 mrad**

$d$ □ $\frac{\lambda}{\theta_0 \Delta\theta}$ $1.2\times10^{-4}$ m

→ [redacted]

# Accurate estimations of the effect

**The wave function of an incident neutron beam at the boundary of media $z=0$**

$$\psi_{in}(x) = A_{in}(x) e^{ik_{0x}x}$$

**To solve the problem of beam reflection expand the field in plane waves.**

**(V.A. Bushuev, A.I. Frank Physics–Uspekhi, 2018, 61)**

$$A_{in}(x) = \int_{-\infty}^{+\infty} A_{in}(q) e^{iqx} dq$$

$$\psi_{in}(x) = \int_{-\infty}^{+\infty} A_{in}(q) e^{i(k_{0x}+q)x} dq$$

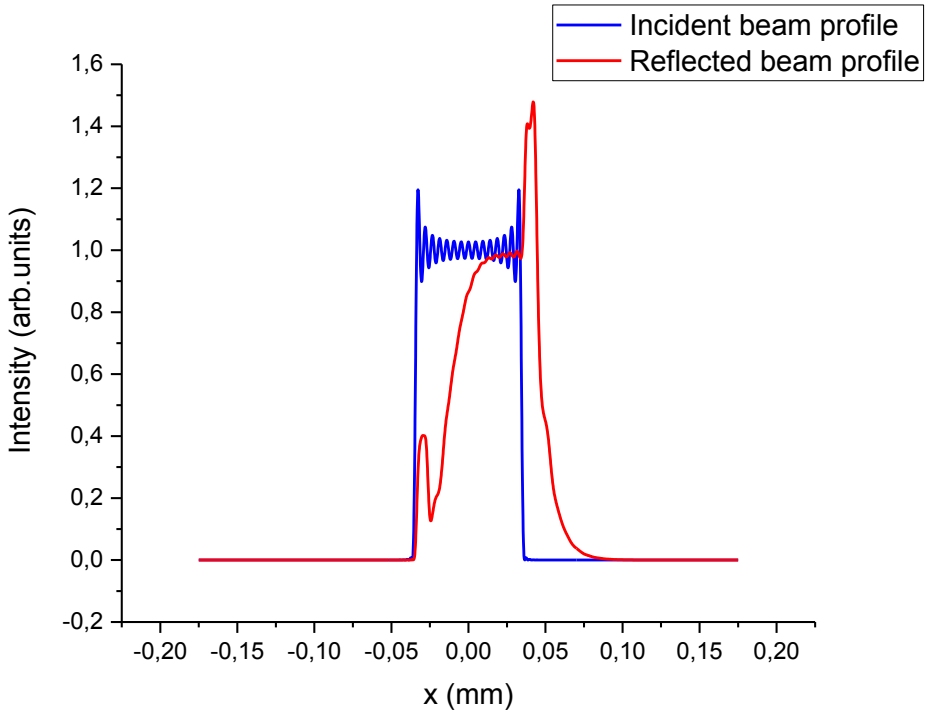
where $A_{in}(q) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} A_{in}(x) e^{-iqx} dx$

**The amplitude of the reflected beam on the surface $z=0$ will be**

$$A_R(x) = \int_{-\infty}^{+\infty} r(k_{0x}+q) A_{in}(q) e^{iqx} dq$$

# Accurate estimations of the effect

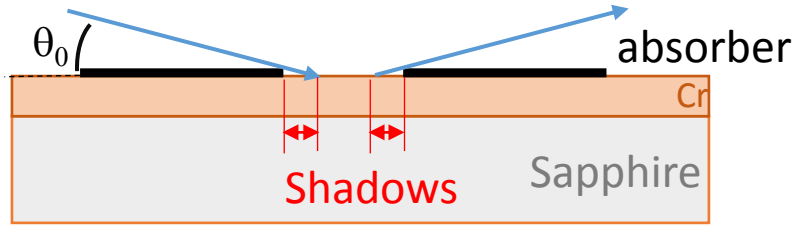
## Rectangular beam profile, width=0.7 мм, Δλ/λ~2%, Δθ/θ~7%




**As can be seen, the reflected beam is shifted along the x axis with respect to the incident beam, and its shape differs from the original profile**

**Estimated effect In the resonance is ~30%**

# Which absorber to use?

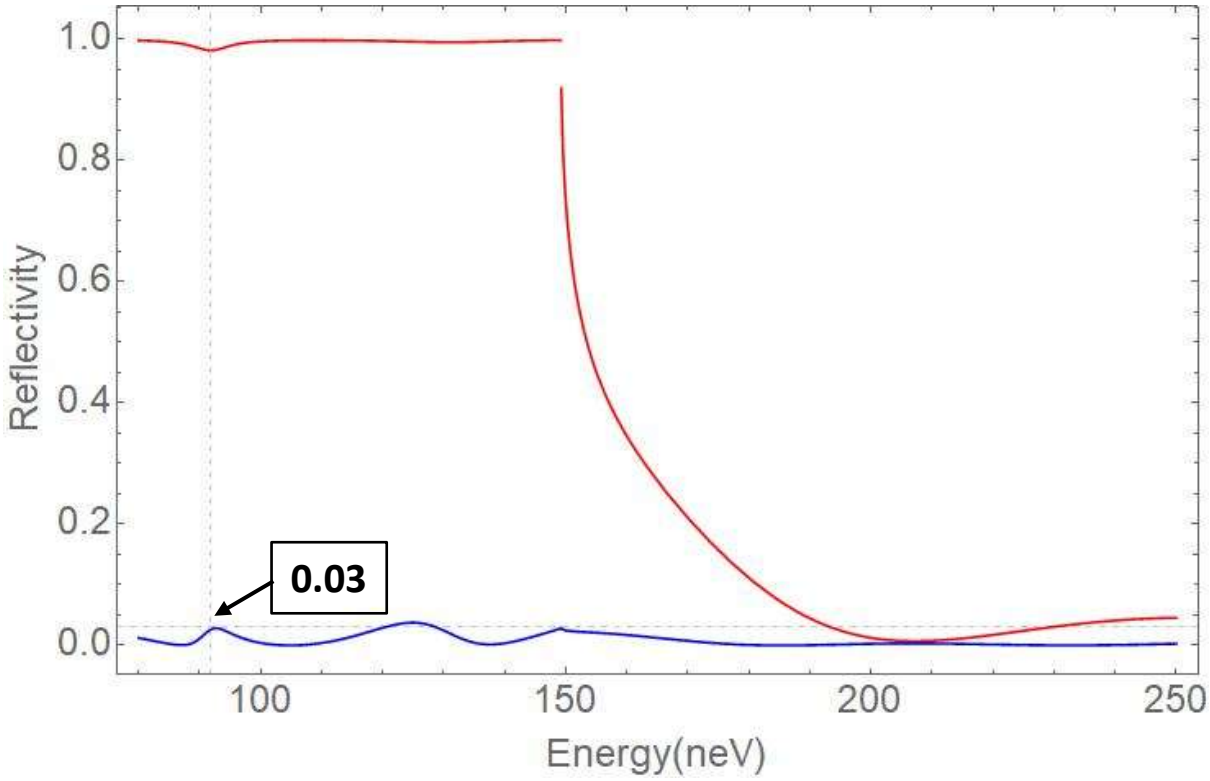



$$\frac{h}{\theta_0}$$ **For the longitudinal shift ξ ~ 0.35 mm $h$ 2 μm**

- **Gd? – very high absorption cross section, but large real part of coherent scattering length**
- **Boron? – Boron-10 is suitable, large absorption cross section (5 times more then for natural), real part of coherent scattering length is very close to zero**

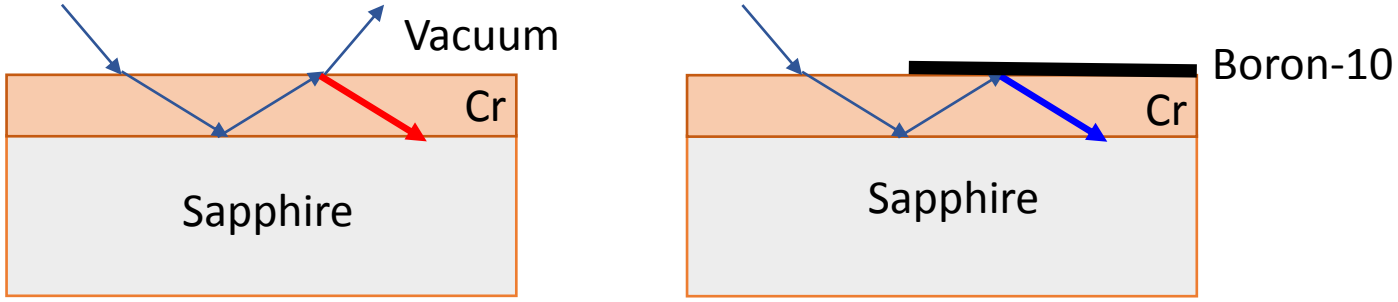
**For 100 nm Boron-10 (2Nσ ~ 80 nm) shadow is 0.02 mm**

# Is 100nm Boron-10 enough?

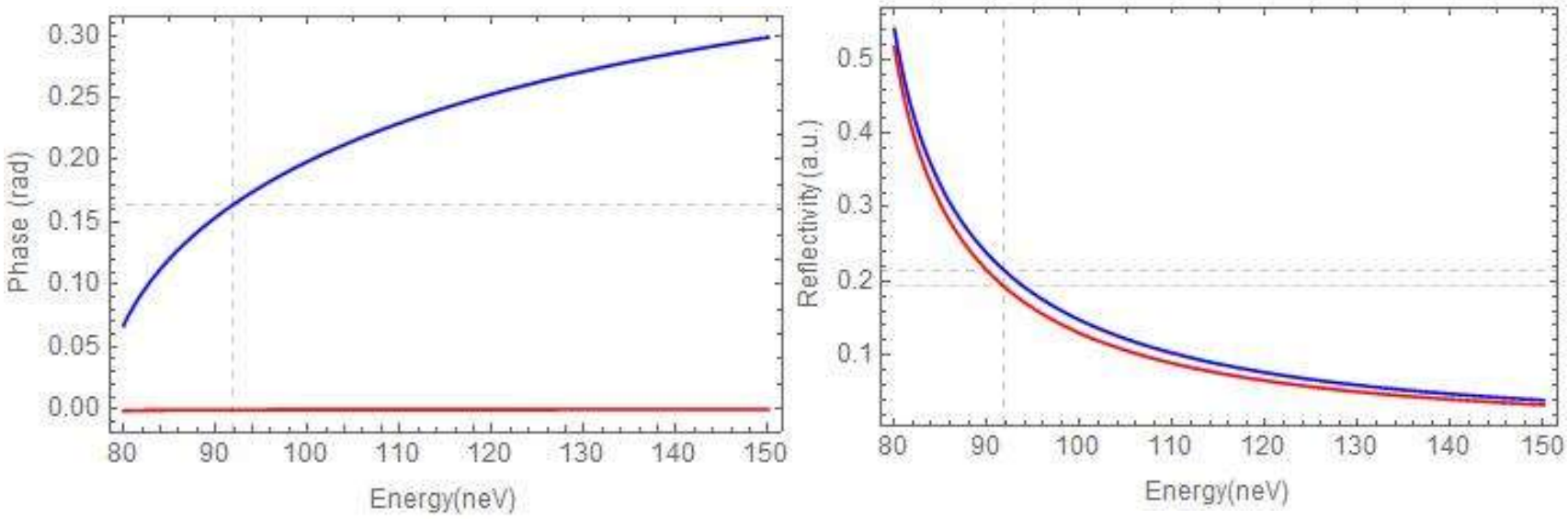



**Reflectivity for $^{10}$B(100nm)-Cr(100nm)-Sapphire and Cr(100nm)-Sapphire were compared**

# Is Boron-10 affect the potential structure and resonance?

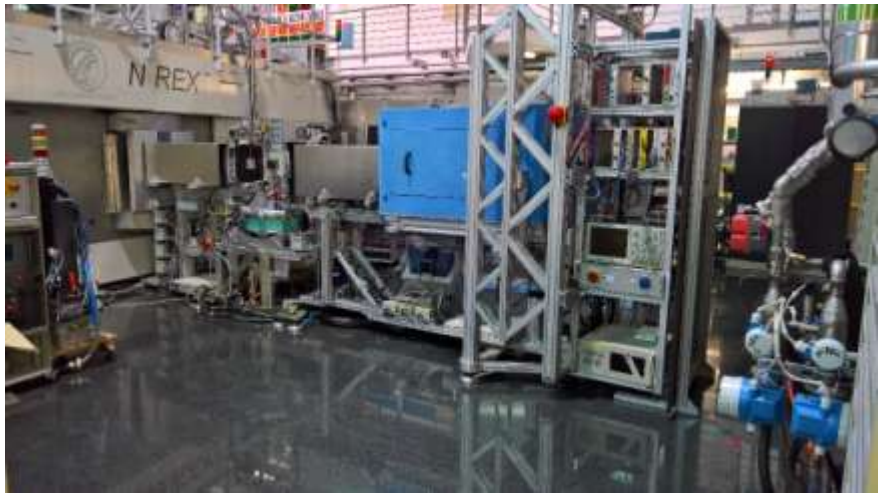


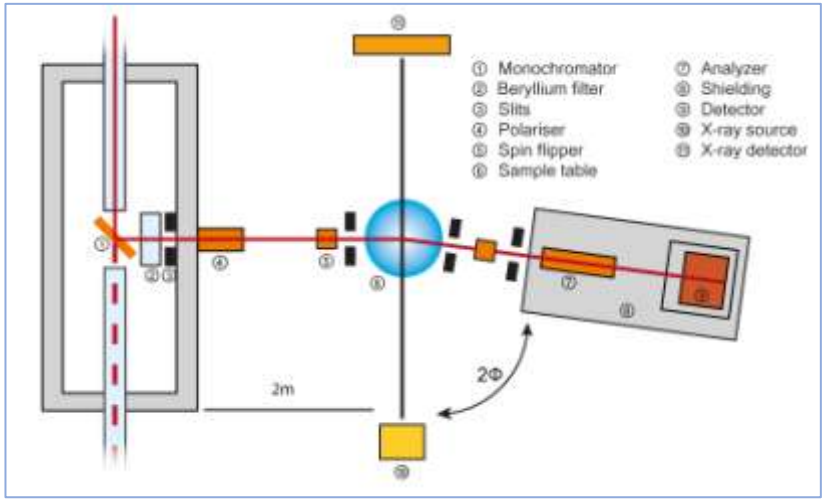

**Reflectivity and phase were compared at the reflection from the interface Cr-Vacuum and Cr-Boron**

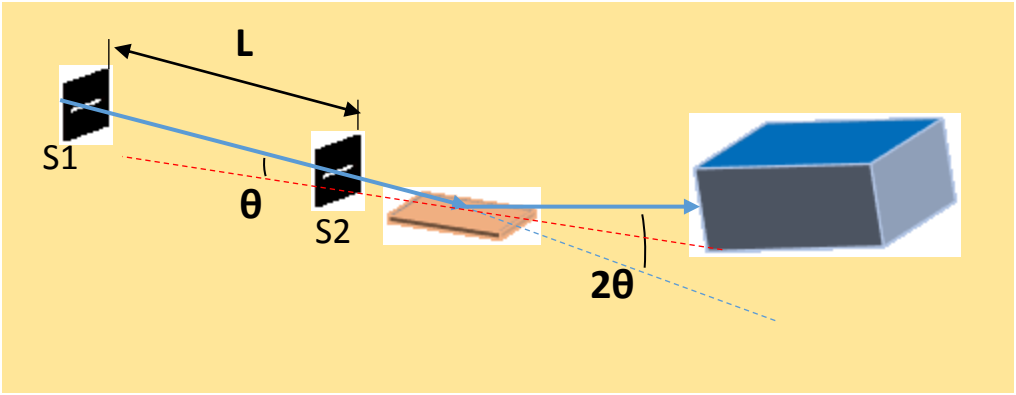



**There differences in phase and reflectivity are small**

# NREX+ Reflectometer (FRM II, Garching, Germany)



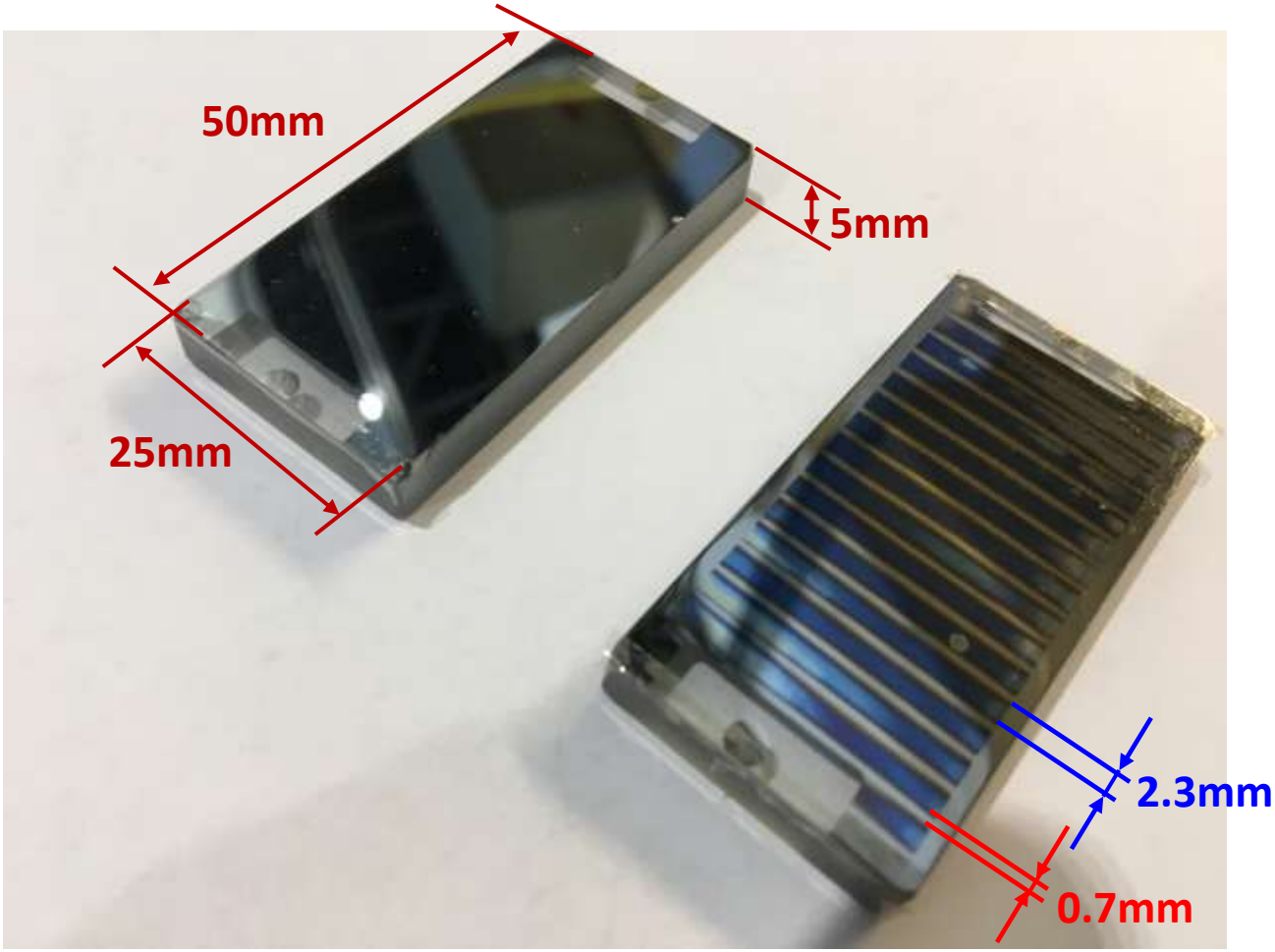




Neutron wave length: **4.3 Å**

Wavelength resolution: **1-2%**

Angular divergence: **0.6 mrad**

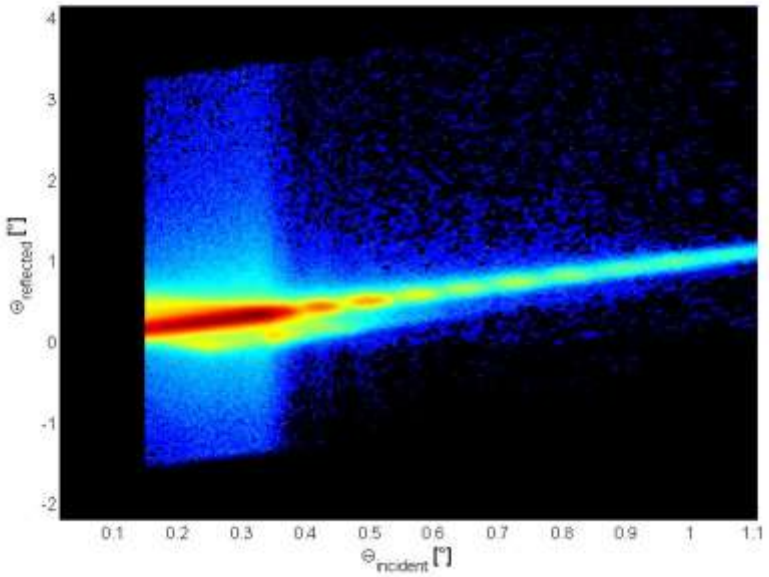
# Samples

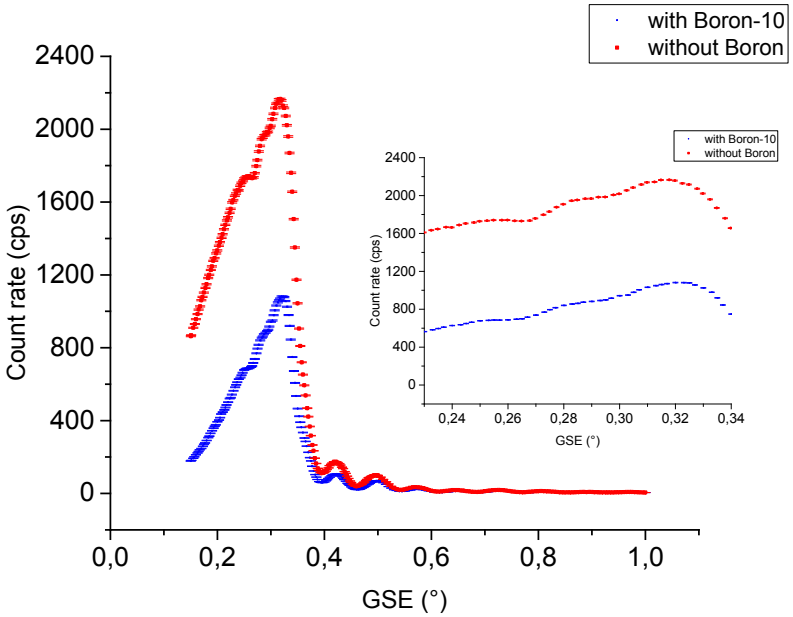



**Chromium (100nm) film on sapphire + Boron-10 (100nm) macro-grating**

# 2D Scattering map & Reflectivity

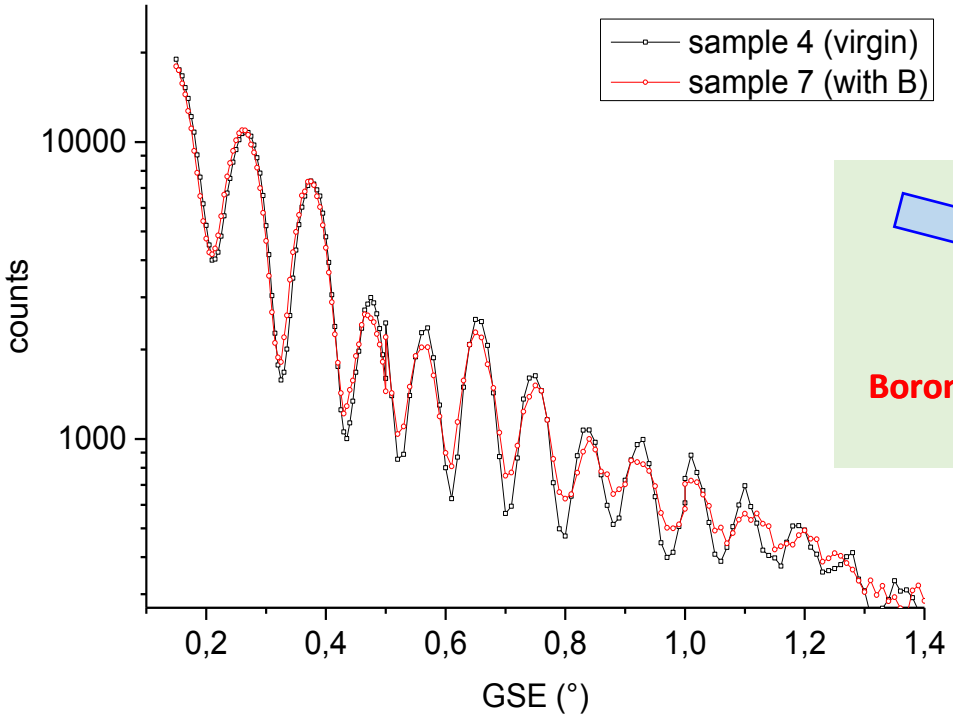
## Measurements of 21-22 may 2018

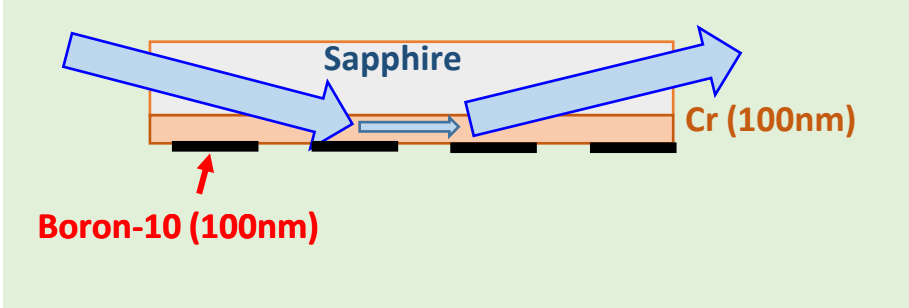



- **Count rate differs in 2 times only**
- **Curves look similar in the region of interest**
- **The sample is of bad quality**
- **The detailed analysis is required.**

# Boron-10 affection on the potential structure




- **150nm of Chromium instead of 100nm**
- **Possible roughness due to Boron implantation to Chromium layer in the sputtering process**

# Summary

- Idea of the experiment on direct observation of Goos-Hänchen shift with neutrons was proposed. It looks reasonable and suitable.
- First test was performed in may 2018.

- Problems with the quality of the sample

- We need in the sample of good quality.
- Some additional theoretical analysis is required

**Thank you for your attention!**